GAS FUEL.

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In attempting to write a paper on this subject, I find that an over-abundance of facts present themselves for consideration, and the principal trouble is to know where to begin—what facts to present—and where to stop.

Gas fuel has been used almost from time immemorial, but the subject of gas firing had recieved but little consideration, and perhaps no thorough scientific investigations until about the time that the Messrs. Seimens began their experiments; from that time on down to about 1883 or 1884, the question interested only certain branches of manufacture, such as steel, glass, etc.

With the introduction of natural gas into workshops, factories and dwellings of Pittsburgh, a new interest was awakened in the subject, and now the great question of the day is, *cheap gas for fuel.*

For almost all purposes, Natural Gas, (such as is obtained from the Devonian rocks of Pennsylvania and from the lower Silurian of Ohio, and Indiana,) is the best fuel in use.

There are purposes, however, for which this gas—and especially some of the Pennsylvania gas—is not well suited.

In fact, so far it has not been possible to smelt ores of iron in a blast furnace, with any natural gas yet discovered, and some of the Pennsylvania gas is not of the best possible composition for puddling iron. It is all successfully used for this purpose simply because it can be had so cheap, but because of the large per cent. of hydrogen that some of the gas is said to contain it can not be so well adapted for puddling as is producer gas, and could the latter be had at the same cost per unit of heat it would be preferable. In fact no gas with a large per cent. of hydrogen is so well adapted to metallurgical purposes where the heat is utilized by *contact with the substance that is to be heated or melted*, as would be gas wholly or largely composed of carbon-monoxide.

Heat units can be obtained from hydrogen when used for industrial purposes, only by uniting it with oxygen, and at high temperatures and in the presence of iron or steel,—as in the puddliug and open hearth steel furnaces,—or in the presence of iron and an excess of carbon, as in the hearth and lower bosh of the blast furnace,—the tendency is to break up, rather than to unite oxygen and hydrogen, either of the elements—(iron and carbon) having a greater affinity for oxygen at high temperatures than has hydrogen. Therefore, when hydrogen is driven into the tuyres of a blast furnace, with the proper quantity of oxygen for union to steam, instead of such union being formed and the temperature increased, the hydrogen passes up the stack uncombined, and in a greatly expanded condition, each cubic foot becoming not less than five and perhaps six feet, each pound carrying away from the hearth where great heat is required, eight thousand to nine thousand units of heat.

Nothing of which we have any knowledge could be put into a blast furnace in a gaseous condition, that could extract so much heat; the specific heat of hydrogen being 3.4 times as great as that of water, and more than seven times as much as that of water vapor.

By the combustion of a pound of hydrogen several times more heat is produced than is obtained by the combustion of any other element,—the temperature resulting being about as high,—and yet if pure hydrogen, with sufficient air to furnish its equivalent of oxygen was blown into a molten mass of iron, cr more particularly a spongy mass of half reduced ore, I assume that it would quickly chill it almost if not quite to a solid.

At present there are in use, for domestic and industrial purposes, four grades or qualities of gases, of which as you have already been told, natural gas is the best. Next to natural gas, coal gas as sold for illumination, is the best gas for heating purposes; the next in order of value being fuel water gas, and last, or the gas of least value being producer gas.

The relative value of these gases, rating natural gas at 100 are a sfollows:

Natural Gas, Findlay.......	100.00
Common Coal Gas..........	65.50
Water Gas................	29.10
Producer Gas..............	12.80

These values are obtained by calculating the quantity of water that can be evaporated at 212 degress Fah. with 1000 feet of the gas, allowing 20 per cent. excess of air; and calculating that the waste gases will leave the furnace or evaporating vessel at a temperature of 500 degrees Fah.

Under these conditions a thousand feet of the gas will evaporate water as follows:

Natural Gas	about....900	pounds
Coal Gas	" 590	"
Water Gas	" 262	"
Producer Gas	" 115	"

The character of all these gases varies more or less,—with loealities —respecting natural gas, and with the modes of manufacture, respecting the other gases.

With these facts before us, what gas do we say should be the fuel of the future? It can not be natural gas, as the territory where it may be found is very limited, and the supply must shortly be exhausted. It can not be coal gas because the cost of manufacture is too great. It can not be water gas because, first: it can not be made cheap enough; and second: the danger to life and property in its use and transportation is too great.

This then, brings us down to producer gas. Shall *it* be the fuel of the future? For metallurgical and industrial purposes, *Yes;* for domestic use, *No;* it is too bulky, too expensive to transport, and the temperature of ignition is too high.

Then what shall the domestic fuel be? *Gas:* a mixture of coal gas, water gas and producer gas. That such a mixture can be made cheaply, will be safe to use, will ignite at a low temperature and can be transported in the piping system now in use by gas companies can be demonstrated by theoretical calculation, and will soon be practically demonstrated by the Fuel Gas & Electric Engineering Company at Pittsburgh.

The specific gravity of the several gases are about as follows:

Coal Gas	.400
Water Gas	.570
Producer Gas	.970
Air being	1.000

The proposed mixture should for domestic use contain about 16 per cent. of coal gas; 34 per cent. of water gas and 50 per cent. of producer gas, and should have a specific gravity of about .750.

Of course to send through the present systems of piping the same quantity of gas of this gravity that had been sent through of illuminating gas, would require a greater initial pressure. Fuel gas would be used more uniformly throughout the 24 hours of the day, than gas is used for lighting purposes, and thereby would greatly increase the capacity of present piping systems.

The mixture described above contains about 7200 heat units, and is a little better than uncarburetted water gas.

The fuel to produce this mixture (at $2 per ton for coal,) would cost about 3 cents per 1000 feet of gas, and the gas could be sold at 25 cents to 40 cents per 1000 feet, and give a fair return on the necessary investment.

The Institute, however, is more interested in the question of gas fuel for industrial purposes than for domestic use, and I will go more into detail in this direction.

I have the drawings of several gas producers, which I have enlarged from printed works so that you can readily comprehend their construction. These are all, with one exception, furnaces for making producer gas,—the exception being the Lowe apparatus for making water gas. I do not present these furnaces because they have any special merit over scores of others, but simply because it was convenient for me to do so.

Number 1, is a furnace invented by Ebelman, and was used in Audincourt, France, as far back as 1840. It was worked with air blast. Dimensions of generator are:—height from hearth to throat 10 ft.; diameter at top of bosh, 3 ft. 4 in.; diameter of hearth about 10 in.

You will observe that a cast iron pipe descends from the top down about four and one-half feet,—into this the fresh fuel was fed. Charcoal was the fuel used and very satisfactory results were obtained.

Number 2, shows the Lowe apparatus for producing water gas. The chamber to the left is the generator proper, and into this the fuel, which may be anthracite coal or coke, is placed. The center chamber is the regenerator or recuperator which is filled with loosely placed bricks, and the right hand chamber is a washer and scrubber for cleaning the gas.

Number 3, shows the front of the Dawson apparatus.

This system of generating gas is said to be coming into use rapidly in England, and especially for generating gas for large gas engines. It really generates a mixture of water gas and producer gas, and when soft coal is used, coal gas is also added to the mixtures. It is said it can be so adjusted as to work continuously. •

Number 4, is the MacFarlane producer. The air is supplied to this furnace by a Kortig blower, and in thus furnishing air it would also supply steam, which in the furnace would be converted into the constituents of water gas, carbon-monoxide and hydrogen. The volatile matter of the soft coal would be forced down through the incandescent fuel to find exit, and all the tar and water would be converted into permanent gas. The construction of the lower part of the furnace is such as to make the removal of the ashes very convenient.

Number 5, shows the construction of the Thwaite Twin furnace. This furnace embodies the same principles as the MacFarlane, that is, the volatile matter is forced down through incandescent fuel in its exit. It has the additional advantage of being able to produce a gas of a more uniform quality, as the chambers may be changed alternately, and thereby insure a mixture containing coal gas at all times.

Numbers 6 and 7, show sections of the Siemens' furnace and valves, the construction of which will be readily understood.

Number 8, shows a section of the regenerative chambers of the Siemens' furnace. The burnt gases, and the air for secondary combustion are made to traverse these checker work chambers alternately, and in this way the heat of waste gases is carried back into the furnace, and by this means only, are the maximum economic resuls obtained, and this assertion will hold good, let the fuel be gaseous or solid.

Number 9, shows a vertical section and the place of the Bicheroux puddling furnace; in this furnace the fuel is converted into gas, and by reason of the close proximity of the solid fuel to the combustion chamber, the heat of the primary combustion chamber, the heat of the primary combustion is utilized.

You will observe that this furnace does not differ in appearance very much from the puddling furnace in use in the Mills of this city. Were the coal receptacles of your common puddling furnaces large enough, so that combustion of the solid fuel could be slower, they could then be worked with ash pits almost closed, and would become fairly good producers. Then could the gases be passed through chambers of checkered brick work, the heat absorbed and returned to the combustion chamber with the air for secondary combustion, you would have all the requisites for reducing the cost of fuel to a minimum.

Number 10, shows a section of Ponsard producer, recuperator and furnace. The combined arrangement is one that commends itself strongly. The producer itself is not unlike the Siemens and I do not think that part of it so good as some others. To my mind the depth of fuel is insufficient to prevent carbonic acid and steam reaching the combustion chamber.

As we are to discuss the question of gas fuel from an industrial standpoint rather than from that for domestic use, we can best illustrate what we desire to present by giving theoretical results posssble to obtain in some branches of manufacturing.

Partly because more gas is used in the metallurgy of iron than for any other purpose, and partly out of deference to the locality of our meeting. I shall discuss the question of gas fuel in its application to a boiling or puddling furnace.

Believing that there are some here who do not know how much easier it is to heat iron than to heat some other substances, and perhaps there are some here who do not understand just what '*specific heat*' and a '*unit of heat*' mean, I will be pardoned and not charged with pedantry if I make a little explanation of these terms.

Specific heat is that quantity of heat required to raise one pound of any substance one degree Fahrenheit. In writing down the specific heat of any substance, we do it in comparison with water. That is to say, water is the unit or standard. If it takes three and four tenths times as much heat to raise one pound of hydrogen one degree fahrenheit, we say the specific heat of hydrogen is 3.4. As it takes but about one thirtieth as much heat to raise a pound of mercury one degree, we say the specific heat of mercury is .033, or about thirty-three thousandths. Now the same quantity of heat that raises a pound of water one degree will raise about ten pounds of iron one degree, so we say the specific heat of iron is .10, or to be exact .1098.

A unit of heat is that quantity of heat that is required to raise one pound of water one degree fahrenheit. Water, you see, is again used as a standard. It is not essential to use a pound of water as a standard, but it must be a fixed quantity. A ton might be usad, but all other substances with which the comparison is mode must also be reckoned in tons.

The comparisons are usually made by weight and not by bulk. Nor must the comparison of a pound of water be made with a cubic foot of gas.

While about explanations I will call your attention to another term which may not be clear to some of you; I refer to latent heat. Latent heat is insensible heat, or heat not measurable with a thermometer. There is the latent heat of liquefaction, or the heat absorbed by a substance in passing from a solid to a liquid, and the latent heat of gasification or evaporization, or the heat is absorbed when a solid or a liquid passes to a gaseous or vaporous condition.

Water in passing from the condition of ice, at a temperature of 32 degrees to a liquid at 32 degrees, absorbs 142.4 units of heat,—hence the latent heat of water is 142.4.

Water in passing from a liquid at 212 degrees to steam at 212 degrees, absorbs 966 units of heat, and therefore we say that the latent heat of steam is 966. We mean that the heat lost or absorbed by one pound of this substance in passing from a liquid to a vapor, and without its temperature being changed, equals the heat that would be requirad to raise 966 pounds of water from the temperature of 32 to that of 33 degrees Fah.

With these explanations we take up the manipulations of the puddling furnace.

The old style of puddling furnaces, such as are in general use in this city, usually charge for a 'heat,' as the boilers term it, 500 pounds of metal, or 'pig,' as it is commonly called.

The coal used in the Mills here is obtained from the No. 5, or lower Kittanning seam. We usually hear the coal spoken of as a *strong* coal. The analysis of this coal shows that it is not the strongest coal in use, and also that it is not the weakest. But so far as my observation goes, there is more coal used to puddle a ton of iron in Ironton, than in any city in the country. At any rate this statement would have been true if made a few years ago. Just why this should be I do not know. The trouble can hardly be with the workmen for puddlers brought here from mills in other localities do no better, and generally not so good work as your home workmen.

I think it is safe to say that it takes 40 bushels of coal to puddle a ton of iron in this city. Forty bushels equals 3200 pounds. If it take 3200 pounds for a ton, it will take 714 pounds to puddle 500 pounds, or one 'heat.'

We will discard the 14 pounds and call it even 700 pounds.

Now let us see how much heat this 700 pounds of coal contains, and to do this we must assume an average analysis, which as given below I believe will not be far from right:

Carbon..........	77.00	per cent.
Hydrogen........	5.00	"
Oxygen..........	10.00	"
Nitrogen........	1.50	"
Sulphur........	1.50	"
Ash............	5.00	"
Total..........	100.00	"

700	lbs.	Coal	77	per cent.	equals	539	lbs. Carbon
700	"	"	5	"	"	35	" Hydrogen
700	"	"	10	"	"	70	" Oxygen
700	"	"	1.50	"	"	10.50	" Nitrogen
700	"	"	1.50	"	"	10.50	" Sulphur
700	"	"	5.00	"	"	35.00	" Ash
Total weight,						700.00	" Coal

But we must deduct from the 35 lbs. hydrogen 8.75 lbs., with which to satisfy the oxygen in the coal. In one pound of hydrogen there are 62032 units of heat. In one pound of sulphur there are 4032 units of heat. From nitrogen and oxygen we obtain no heat. Then:

539.00 lbs. C. $\times$ 4500=7,815,500 heat units from carbon.

35.00 lbs. H—8-75 $\times$ 62032=1,628,340 heat units from hydrogen.

10.50 S $\times$ 4032 = 42,336 heat units from sulphur.

Total heat units from the coal equal 9,486,176. In round numbers there are 9,500,000 heat units in the 700 pounds of coal used in puddling 500 pounds of 'pig.' How much of this heat is actually used in melting and working this metal.

The mixture of metal used in this city will melt at about 2000 degrees temperature, but as the iron begins to come to 'nature' as it is termed, a much higher heat is required to keep it in a semi-molten state, and we will assume that even 2800 degrees are required to keep it in condition for 'balling.' We start into the process with the pig at 60 to 80 degrees temperature, and the carbon of the pig furnishes a good many heat units, but both of these items we will ignore,, as ignoring them will not materially effect the result to be obtained.

To heat water up to 2800 degrees,—assuming we could keep it a liquid and that its specific heat was constant,—would reqnire 2800 units for each pound. But I have already explained that iron requires but about *one-tenth* the heat required by water to raise it one degree Fah. Then, if this be true, iron will require but 280 units for each pound of metal; then 280 times 500 pounds of metal equals 140,000 units. To this we must add the latent heat of liquefaction, 233 units × 500 pounds = 116,500 units, making the total heat utilized in puddling 500 pounds metal, 256,500 units of heat.

If we get from 700 pounds of coal 9,500,000 units of heat we get from one pound No. 5 coal 13,570 units. Then by dividing 256,500 by 13,570, the answer is 19, nearly, which represents the pounds of coal that are utilized. *Nineteen pounds out of 700! What sinful wastefulness!* Less than 3 per cent.

Some of these puddlers, or rolling mill managers, probably the latter, lie uneasily in their graves a thousand years from now, when posterity is crying for fuel. Possibly these spendthrifts will not be unwilling to spare their posterity some of the heat of which they may at that time be possesed,—the legitimate fruit of their wastefulness.

If it be true, as we so often hear it asserted, that nothing is ever wasted or lost in nature, then we can see the consistency of the doctrine deduced from the old 'EDITION.'

The fuel that these fellows waste or permit to be wasted in this life, will be stored up to their credit, and for their utilization in the life to come.

The question that naturally arises in our minds is: What becomes of the other 97 per cent. of the heat of our coal?

It goes up the stacks very largely —at one time as half burnt gases and at the next moment as heated air. At one moment there is an insufficient supply of air., or if but enough is present the arrangement for properly mixing the air and gases are deficient and the fuel escapes oxidation.

At another moment the air present is greatly in excess of the requirements of the fuel, and this excess must be heated to the temperature or your furnaces.

The weight of the gaseous products, if the proper quantity of air has been admitted for the complete combustion of 700 pounds of coal, would be about 8400 pounds. The specific heat of these gases is about .245. Then to raise this 8400 lbs. one degree will require 2000 units of heat, and to raise it 2800 degrees, that is to the temperature that we have already agreed we must have in the puddling furnace, would require 5,600,000 units of heat. Here then we account for the loss of more than half your fuel, as these gases unquestionably do leave your metal at a temperature equal to or above 2800 degress.

Now you will remember that we have this loss when admitting only the proper quantity of air for combustion with the fuel, but it is generally conceded that in burning solid fuel we admit from 50 to 100 per cent. too much air. We will assume in this instance, that only 50 per cent. excess of air is admitted and then see what the loss must be. With this excess of air the gaseous products from your 700 pounds of coal will weigh 12,250 pounds. The specific heat will be a little lower now, say about .243. In round numbers then it will require 3000 units of heat to raise this 12250 pounds of gases one degree, or 8,400,000 units to raise these products 2800 degrees.

Remember you had but about 9,-500,000 units of heat all told, in your coal. With these figures in your mind, you can see the vast importance of some system of recuperation by which this enormous quantity of heat can be returned to your furnaces there to be utilized.

In determining the quantity of heat actually utilized in puddling 500 pounds of metal, to be equal to that furnished by 19 pounds of coal, I have overlooked the fact that the specific heat of the metal changed somewhat as its physical and chemical condition changed in the furnace, and it would be only fair to increase the 19 to about 20 pounds, but even then the per cent. of the whole quantity generated is insignificant.

Remember I have been discussing the Ironton practice of puddling. There are places working solid fuel where they get about 4 per cent. of the value of the fuel in single furnaces and 4¼ to 5 per cent. in double puddling furnaces, and 8 to 10 per cent. in heating furnaces.

You have been shown what is done with solid fuel and we now undertake to show what possibly may be done with gaseous fuel and recuperation.

One ton of No. 5 coal, not the lump, but nut and slack mixed, will make 125,000 feet of producer gas, that will contain 2000 units of heat per pound of gas. The 125,-000 feet will weigh about 10,000 pounds. If one pound contains 2000 units of heat 10,000 pounds will contain 20,000,000.

You will remember that the 700 pounds of solid coal, contained 9,-500,000 units; that would be in the proportion of about 27,140,000 units for a ton, while the gas from a ton of slack contains but 20,000,-000 units of heat. Part of this loss is due to the difference in the character of the coal, but most of it is due to the loss of primary combustion.

But should your producers be put near your furnaces, then this heat could be saved, and by passing the gases to the furnaces at a temperature of, say 700 degrees, you would add to the 20,000,000 units 1,715,000 units of heat, making the total heat 21,715,000 units.

Now in burning this gas instead of using an excess of air, amounting to 50 per cent., you need not give it more than 10 per cent. excess. Then with this same excess of air, the total weight of the gaseous products of combustion will be about 25,000 pounds, and the specific heat will be about .245.

Now these products will leave your furnace at as high a temperature as it left the furnace when using the solid fuel, but we propose to return the heat by the interposition of recuperators. The entire weight of gaseous products heated up to 2800 degrees (and in this instance they will be much above that temperature,) will contain 25,000 times .245, multiplied by 2800, which equals 17,150,000 units. Now, let these gases escape from the recuperators at a temperature of 800 degrees and we return 12,-250,000 units to your furnace, with the air and with the primary gases if they also passed through the recuperators.

We have already seen that but 256,500 units of heat are required for melting and puddling a 500 pound charge.

We have put 21,715,000 units into the furnace and have lost in the waste gases, which finally left the recuperator at an 800 degree temperature, 4,900,000 units, leaving us a net heat of 16,815,000 units. But so far we have allowed nothing in any of these calculations for radiation and imperfect combustion. The first should equal ten or fifteen per cent., and the second from five to ten per cent. But we will more than double these quantities and say that the loss from radiation, imperfect combustion, and accidental causes, will equal 50 per cent. of the entire quantity of heat of the combustion chamber. Deducting this from the quantities of heat given above as net result, and you have about an even 6,000,000 units left for utilization.

If it took 256,500 units to puddle 500 pounds it will take 513 units to puddle one pound. Then dividing the 6,000,000 units by 513 we get 11,700 as our answer, which represents the weight of metal in pounds that should be puddled with one ton of nut and slack coal, being nearly 6 tons (I refer all the time to net tons of 2000 pounds.) That such work ever has been done I shall not claim; that such work may be done with proper facilities, cannot be rightfully questioned. There are reasons, however, which make it more difficult to realize the full value of fuel in puddling iron than in some other industrial operations. During certain stages of the work it appears to be necessary to heat only with a reducing flame. Yon have all noticed that there are certain parts of the work of puddling that is always done with the damper down. During that time the puddler is using a reducing flame, and while it is not so hot as an oxidising flame, yet his iron will remain liquid with that flame when it would not do it with an ordinary oxidising flame.

When you have changed your furnaces to accord with the principles brought into prominence lately by Frederick Siemans, that is that heating should be done by radiation and not by contact, then it will not be of any consequence, or rather it will then be unnecessary to work with a reducing flame.

To introduce this principle the tops of the furnaces must be elevated and not depressed.

To sum up: To first put your fuel into a gaseous condition is a long stride toward economy; to have good recuperation is still better; to have both is essential in this locality, if you expect to keep step with modern improvements and be able to successfully meet your competitors in markets of the country.